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Diverse configurations of the boiler feed pump drive for the ultra-supercritical 900-MW steam plant

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Abstract

Coal-based electric power generation remains the basic source of obtaining energy. With increasing pressure to reduce CO_2 emissions, improving power unit efficiency has become an issue of utmost significance. Surely, one of the possibilities to improve the efficiency of new power units is raising the steam parameters. With improved power plant efficiency, there is a lower demand for power of almost all auxiliary equipment except the boiler feed pump. The reason for this is that the power needed to drive the feed pump is an almost linear function of the steam pressure. This means that, even though the steam mass flow (and, consequently, the feed water mass flow) is reduced and the efficiency of feed pumps is improved, their power increases. For this reason, it is very important to find the optimum drive of the boiler feed pump. The main aim of the conducted analysis was to compare various drive options of the boiler feed pump for a conceptual ultra-supercritical 900-MW steam power unit. The following drive configurations of the boiler feed pump were presented and compared:

- A frequency-controlled electric motor
- A condensing turbine fed with steam extraction from the immediate-pressure turbine
- An extraction-backpressure turbine fed with steam from a cold reheat steam line with bleeds shifted from the low-pressure turbine
- A backpressure turbine fed with steam from a hot reheat steam line operating in parallel with the intermediate-pressure turbine
- An extraction-backpressure turbine fed with steam from a cold reheat steam line with bleeds shifted from the intermediate-pressure turbine (the master cycle idea).

The analysis of the operation of the 900-MW unit with various configurations of the feed pump drive was carried out for three load levels: for the nominal mass flow of live steam and for the partial mass flow of 75% and 50%.

Keywords: Ultra-supercritical coal-fired power units, Boiler feed pump drive, Master cycle, Net efficiency of electric power generation

Background

The perspective of ever more stringent restrictions on emissions and of the rising coal consumption pose a challenge to the professional power engineering and necessitate the search for effective and economically acceptable methods of reducing CO_2 emissions. In the next years to come, condensing coal-fired power units will still be the pillar of the Polish electric power system. In the present situation, it is, therefore, necessary to achieve better and better efficiency of electric energy generation which will have a critical significance in meeting the emission-related requirements. Undoubtedly, raising the steam parameters is the main driving factor in the efforts to increase efficiency. Thus, the construction of new generation coal-fired units for ultra-supercritical parameters is a matter of the next few years to come. The efficiency of power generation in conventional coal-fired units has increased in the last 10 years by approximately 7% points. The power units which are now being built in the pulverized coal-fired (PF) technologies reach a capacity of the order of 1,000 MW. The pacemakers in the

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electric power generation net efficiency are now: Nordjyland in Denmark (47% for hard coal) and the BoA power unit in Niederaussem, Germany (45.5% for brown coal) [1].

Improving a power unit efficiency results in a reduction in fuel and steam consumption per unit which involves a reduction in the mass flow of burned fuel, feed water and other combustion products: slag and ash. The expansion of regenerative systems and the raising of feed water temperature additionally result in reducing the mass flow of the main condensate and of the mass flow of the water cooling the condenser. Generally, an effect of an increase in the steam parameters is a decreased demand for power to satisfy the needs of most facilities. However, there is a greater need in terms of the power with which the feed water is pumped. Since the power of the boiler feed pump is an almost linear function of the live steam pressure despite a reduction in the unit steam consumption and the feed water consumption, as well as an improvement in the efficiency of the pump itself, its share in the total demand for power to satisfy own needs increases substantially.

Boiler feed pump drives currently in use

The feed water system is one of the critical components of a power unit. Its properties decide about many parameters of the thermal cycle but also about a failure-free and safe operation of the power plant. Therefore, the problem of the selection of the boiler feed pump drive is one of the most important issues in designing power units.

Due to the requirements, each power unit should be equipped with at least two boiler feed pumps whose nominal capacity should ensure the maximum capacity of the once-through boiler. The value of the pumping effective pressure is included in the range of 1.1-1.4 of the steam pressure rating in the boiler. The efficiency of modern feed pumps exceeds 85%. The demand for power while pumping feed water is from 2% to 4.2% of the power generated by the unit [2]. Consequently, the driving motor of the feed pump is usually the principal receiver of electricity in the power plant.

In high power units, an extra low speed booster pump is used to prevent cavitation. The pump, which features an inlet designed specially to avoid cavitation, feeds water into the main pump, thus, protecting it entirely from this phenomenon. The booster pump may have a separate drive, or it can be driven by the main pump driving motor through a speed reduction gear [3].

To drive boiler feed pumps in power units with a capacity of up to approximately 250 MW, induction squirrel-cage motors and a fluid coupling to adjust rotation speed are used almost exclusively. However, as the power capacity of newly constructed units grew, the lack of appropriate electric motors (EM) became a problem. For this reason, for power units with a capacity exceeding 300 MW, steam drives were applied by means of a separate turbine incorporated into the thermal cycle. The steam turbine starts to drive the feed pump only after a sufficient amount of steam has become available. Due to that, it is necessary to use an additional start-up pump with a partial capacity of 30% to 50% with an electric drive. The driving turbine of the boiler feed pump can be incorporated into the thermal cycle in two ways [2]:

- As a condensing turbine (CT), fed with steam from the intermediate-pressure turbine (outlet steam is condensed in a separate condenser or it is introduced into the main condenser)
- As a backpressure turbine (BPT) or extraction-backpressure turbine (EBPT), fed with steam from the high-pressure turbine (outlet steam and steam bleeds, if any, are condensed in low-pressure regenerative heaters).

Because condensing turbines used to drive boiler feed pumps have a limited effect on the thermal cycle of the unit, they have found a much wider application in the professional power engineering. In Poland, this configuration was used in the units of the power plants in Bełchatów, Opole, Pątnów and Łagisza.

Another possible option is the feed pump driven by the shaft of the main turbine. The pump can be joined to the turbine shaft either at the high- or low-pressure turbine side. Both solutions were used in the past, but both increased costs and the turbo set complexity. A gear had to be applied because of the difference in the speed of the turbo set and the pump. As these solutions involved a bigger investment outlay and higher operational costs, they are no longer used. Their substantial drawback was also the forced and extremely unfavorable location of the feed pump in the powerhouse which caused additional construction problems.

Condensing turbines to drive boiler feed pumps are usually fed with the steam from the outlet of the intermediate-pressure turbine or steam from the intermediate-pressure turbine bleeds, and they give steam to the main or additional condenser. The amount of steam needed to drive the condensing turbine reduces the mass flow through the low-pressure turbine and can contribute to a reduction in the total discharge loss and, consequently, reduce the heat consumption per unit. Therefore, an application of a condensing turbine to drive the feed pump is more effective if the low-pressure turbine is heavily loaded.

Under a low load of the unit, the steam mass flow through the low-pressure turbine is usually not big enough which causes the danger of a substantial increase in the temperature of the blades. As a rule, the problem is solved

by increasing the steam mass flow from the intermediate- to the low-pressure turbine. Under low loads of the unit, there may then be not enough steam fed into the turbine driving the feed pump which necessitates an introduction of additional steam into it. This may cause mechanical problems because the turbine driving the boiler feed pump was designed for lower parameters of the incoming steam. In consequence, additional facilities are required for the system, which increase the investment costs of the plant. Another option in this situation is a transition to an electric drive of the boiler feed pump.

The large mass flow of the steam needed to satisfy the pump's demand for the driving power causes the volume of the outlet steam mass flow to increase significantly, which results in a large annulus area and, consequently, in high blades of the last turbine stage. In the case of high power units, the relatively high rotation speeds of the boiler feed pump (up to as much as 7, 300 rotations per minute) are not suitable for the condensing steam turbine. Due to the high rotation speed required by the pump, the peripheral velocities of the last stages differ considerably from the optimum values that ensure the highest efficiency. Combining high peripheral velocities with high blades often causes mechanical problems. To avoid them, some manufacturers offer turbines with the flow separated in the last stage into two stages with a smaller diameter. This sometimes solves mechanical problems with high blades, but due to the flow losses resulting from the separation of the steam mass flow, no improvement in efficiency is achieved. In fact, the efficiency of condensing turbines which drive boiler feed pumps is often by 6% to 7% points lower than that of the main steam turbine [4]. Some manufacturers offer reaction-type condensing turbines with a fully separated flow with the steam inlet in the middle and symmetrical outlets. This leads to the rotor elongation, which is not a problem in the case of reaction constructions because they solve the mechanical problems related to long blades and ensure an efficiency level which is 2% to 3% points, different from the efficiency of the main turbine [4]. However, such machines are very expensive.

In recent years, both the power capacity of available electric motors and the efficiency of low-pressure turbines and drive control have increased substantially. Table 1 presents example efficiency values for turbine and electric drives. The efficiency of modern electric motors is much better than the one of motors coming from earlier batches which is still used in electric power stations. The efficiency of the motors offered today exceeds 97%, while older motors reached the efficiency level in the range of 91% to 94%. Moreover, the characteristic curves of the efficiency of modern motors have a flat course, which is of utmost importance for operation under a partial load [5]. Hence, the overall efficiency related to electric motors driving boiler feed pumps has improved. On the other hand, the efficiency of turbines driving BFPs has not changed much. Therefore, in the latest constructions of high capacity power units for supercritical parameters, especially German ones, the system which is most often used is the $2 \times 60\%$ or $2 \times 50\%$ one, with an electric drive and rotation speed controlled by frequency, as this kind of speed control has a fairly flat efficiency characteristic in a wide range of loads compared to the fluid coupling. The adjustment of the pump efficiency is carried out through the control of the frequency and voltage of the current powering the electric motor in order to obtain the required rotation speed. The pump is connected to the driving motor through an elastic coupling to reduce the torsional harmonic forces transmitted by the pump. Changing rotation speed is the most effective and economical way of adjusting the pump efficiency. Adjustments made to rotation speed cause only a slight decrease in the pump efficiency compared to operation with fixed revolutions. A change in rotation speed involves a change in the pump characteristic. This type of control allows a reduction in electricity consumption in a wide range of loads. Usually, frequency-controlled synchronous motors are used for such solutions. The rotation speed of a synchronous motor can be reduced from the nominal value to very low speeds by reducing the frequency and voltage of the electric current powering the motor [5].

The improvement in the reliability and availability of the pumping engine components, which is a part of the general technological progress, has caused that the availability of the $2 \times 60\%$ ($2 \times 50\%$) systems driven with electric motors is only slightly different from the values achieved by the EM $3 \times 50\%$ or BPT $100\% + \text{EM } 30\%$ configurations. On the other hand, the investment expenditures for the EM $2 \times 60\%$ (EM $2 \times 50\%$) systems are much lower compared to the other two [6]. For these reasons, in many recent constructions of high capacity power units, it was the pump driven by a frequency-controlled electric motor that was selected, not the pump driven by the turbine. Despite the electric power losses in the generator, transformer, supply network, frequency converter and motor, this

Table 1 Comparison of boiler feed pump drive efficiency [6]

Efficiency	Condensing turbine	Electric drive
Low-pressure turbine	-	88 - 92
Generator	-	98.5
Transformer	-	99.5
Motor	-	97
Drive control	-	95 - 96
TOTAL	83	74 - 84

system is sometimes more efficient than the feed pump driven by a condensing turbine.

Alternative options of the boiler feed pump drive

The assessment of the possibility of a further improvement in the net efficiency of electricity generation in conventional coal-fired units for ultra-supercritical parameters calls for consideration of options of the boiler feed pump drive other than the most often used ones, namely those powered by the electric motor and by the condensing turbine.

One of them is an application of the aforementioned backpressure turbine or extraction-backpressure turbine fed with outlet steam from the high-pressure turbine from the cold reheat steam line. The outlet steam together with the driving turbine bleeds (if any) would condense in low-pressure regenerative exchangers. Owing to the fact that outlet steam also gives up heat in the regenerative system, the extraction-backpressure turbine does not require a costly system of the condenser and cooling water which usually is the case with the condensing turbine driving the main feed pump.

An interesting option could be the implementation of the 'master cycle' (MC) solution patented by the company Elsam Engineering (Fredericia, Denmark), which consists in shifting all the intermediate-pressure turbine bleeds to an auxiliary extraction-backpressure turbine referred to as 'tuning turbine' which is also fed with the steam from the high-pressure turbine outlet [7-9]. The auxiliary turbine drives the main boiler feed pump and, optionally, an auxiliary generator which could carry away the power surplus generated by the system to the unit transformer through separate, additional primary coils. During the start-up or holdup of the unit, the 'synchro-self-shifting' clutch is open and the auxiliary turbine does not work. The auxiliary generator is switched to motor operation and drives the main feed pump, which renders the start-up feed pump driven by an electric motor unnecessary. The use of an additional generator on a single shaft together with the pump and the turbine would require revolution control to maintain a steady speed on the part of the generator.

A solution like this has many advantages because a substantial rise in the temperature of steam, especially reheated steam, increases the problem of the difference between the bleed steam and the saturation temperatures in regenerative heaters fed with bleeds from the intermediate-pressure turbine, which are situated right after the steam reheater. This causes material and thermodynamic problems because, with the rise in the mean difference in temperature of the heat-exchanging agents, the exergy losses rise too which leads to a reduction in the process effectiveness and to an increase in the heating steam consumption. By keeping pressures in the bleeds of the auxiliary turbine at the same level as in the intermediate-pressure turbine, the temperature difference in the exchangers will be much lower (the outlet of this turbine is even in the area of saturated steam). Another advantage of the master cycle is that the construction of an intermediate-pressure turbine without bleeds is much simpler and cheaper. This is essential in view of the need to use expensive construction materials. Lower temperatures of the steam in the bleeds from the driving turbine, compared to the intermediate-pressure turbine, result in an increase in the mass flow from them. This causes a reduction in the steam mass flow to the reheater, i.e., lower costs of the reheated steam pipelines and of the reheater in the boiler. The steam mass flow from the main turbine into the condenser is also smaller which decreases heat losses of the cycle.

Yet, another solution is the use of a backpressure turbine working in parallel with the intermediate-pressure turbine. The driving turbine is fed with steam from a hot reheat steam line. Outlet steam from the turbine is in turn introduced into the inlet of the low-pressure turbine. Such a configuration limits the problem of too little steam fed to the low-pressure turbine at low loads of the unit. What can be a problem, however, are the high parameters of the inlet steam (identical to those at the inlet to the intermediate-pressure turbine), which is related to the use of expensive construction materials.

An analysis of selected configurations of the boiler feed pump drive

In order to assess the impact of the boiler feed pump drive configuration on the net efficiency of electric power generation, balance calculations for a unit for ultra-supercritical parameters were carried out. The subject of the study was a conceptual coal-fired unit with a net electric power capacity of 900 MW. The basic parameters of the unit are listed in Table 2. The system has a single inter-stage steam reheat, a four-stage low pressure regeneration and a three-stage high pressure regeneration, plus a steam desuperheater.

Five configurations of the boiler feed pump drive were analyzed:

- A frequency-controlled EM (Figure 1)
- A CT fed with steam extraction from the immediate-pressure turbine (Figure 2)

Table 2 Basic parameters of the conceptual 900-MW unit

Live steam pressure	30 MPa
Live steam temperature	650°C
Reheated steam pressure	6 MPa
Reheated steam temperature	670°C
Pressure in the condenser	0.005 MPa
Feed water temperature	310°C
Net electric power	approx. 900 MW

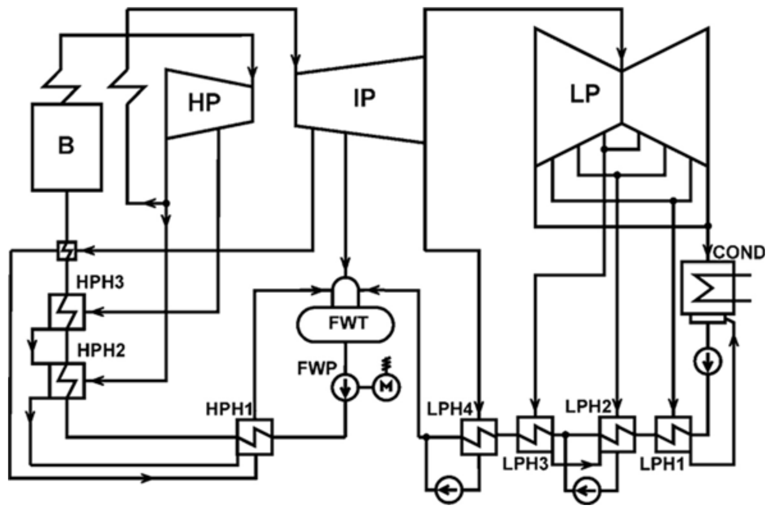

Figure 1 Diagram of the thermal cycle of a 900-MW unit with feed pump driven by EM. B, boiler; HP, high-pressure turbine; IP, immediate-pressure turbine; LP, low-pressure turbine; HPH3, HPH2 and HPH1, high-pressure feed water heaters; FWP, feed water pump; FWT, feed water tank + deaerator; LPH4, LPH3, LPH2 and LPH1, low-pressure feed water heaters; COND, condenser.

- An EBPT fed with steam from a cold reheat steam line with one bleed and an outlet directed to low pressure regenerative exchangers (Figure 3)
- A BPT fed with steam from a hot reheat steam line operating in parallel with the intermediate-pressure turbine (Figure 4)
- An application of the idea of the MC: an extraction-backpressure turbine fed with outlet steam from the high-pressure turbine with bleeds and an outlet directed to regenerative exchangers which, in a classic system, are fed from the intermediate-pressure turbine (Figure 5).

Figures 1, 2, 3, 4 and 5 present simplified diagrams of the thermal cycle of a 900-MW unit for the boiler feed pump drive configurations under consideration.

Methods and assumptions in the cycle analysis

The calculations of the cycle for selected configurations of the boiler feed pump drive ware conducted with the software Gate Cycle v. 5.40 (GE Company, Billerica, MA, USA). The software is used for balance calculations of electric power systems and makes it possible to model their operation under various loads.

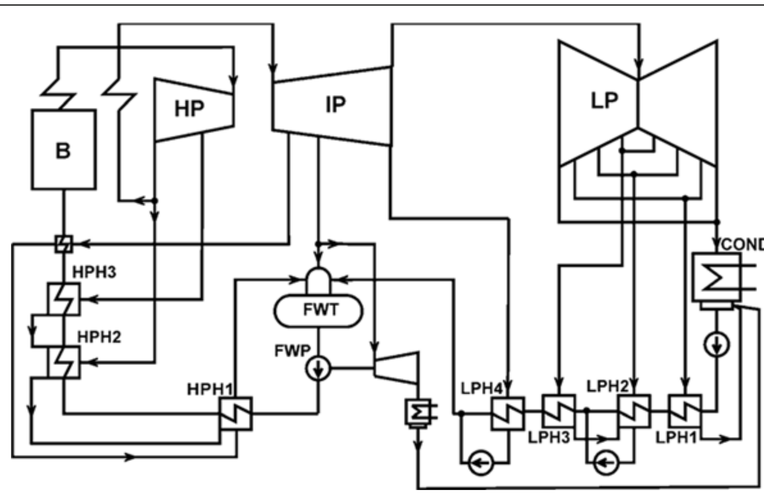

Figure 2 Diagram of the thermal cycle of a 900-MW unit with feed pump driven by CT. B, boiler; HP, high-pressure turbine; IP, immediate-pressure turbine; LP, low-pressure turbine; HPH3, HPH2 and HPH1, high-pressure feed water heaters; FWP, feed water pump; FWT, feed water tank + deaerator; LPH4, LPH3, LPH2 and LPH1, low-pressure feed water heaters; COND, condenser.

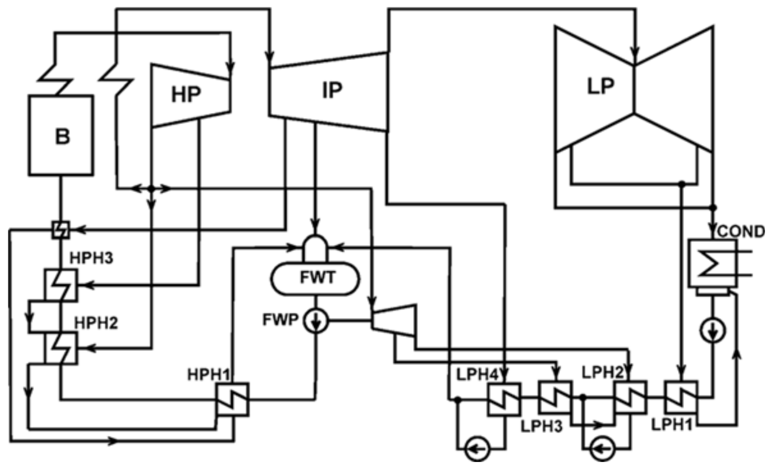

Figure 3 Diagram of the thermal cycle of a 900-MW unit with feed pump driven by EBPT. B, boiler; HP, high-pressure turbine; IP, immediate-pressure turbine; LP, low-pressure turbine; HPH3, HPH2 and HPH1, high-pressure feed water heaters; FWP, feed water pump; FWT, feed water tank + deaerator; LPH4, LPH3, LPH2 and LPH1, low-pressure feed water heaters; COND, condenser.

The analysis of the cycle was conducted with an assumption that for each unit configuration the nominal mass flow of live steam was identical. The efficiencies of the groups of turbine stages as well as the pressures in corresponding bleeds in individual unit configurations have the same values so do all the live steam parameters, the pressure in the condenser, the temperature of the water feeding the boiler and the boiler efficiency.

The calculations were made for the nominal mass flow of live steam produced by the boiler and for the partial mass flow of 75% and 50%. For the needs of the analysis, it was also assumed that, for each configuration, the system had the same boiler feed pump that ensured a 100% efficiency of the steam boiler, and the booster pump had a separate electric drive. In the case of the variants with the turbine drive of the feed pump, the turbine generates power needed only to drive the pump and does not generate extra electricity.

In order to calculate the net electric power and the net efficiency of the unit, an assessment was made of the demand for electric power of all the basic auxiliary equipment: the boiler feed pumps: both booster and main (for the EM variant), the condensate pumps, the pump of the water cooling the condenser, the air and flue gas fans,

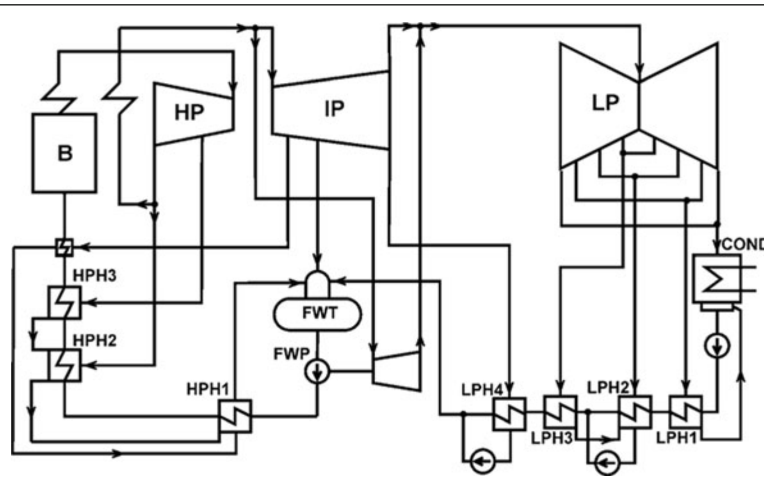

Figure 4 Diagram of the thermal cycle of a 900-MW unit with feed pump driven by BPT. B, boiler; HP, high-pressure turbine; IP, immediate-pressure turbine; LP, low-pressure turbine; HPH3, HPH2 and HPH1, high-pressure feed water heaters; FWP, feed water pump; FWT, feed water tank + deaerator; LPH4, LPH3, LPH2 and LPH1, low-pressure feed water heaters; COND, condenser.

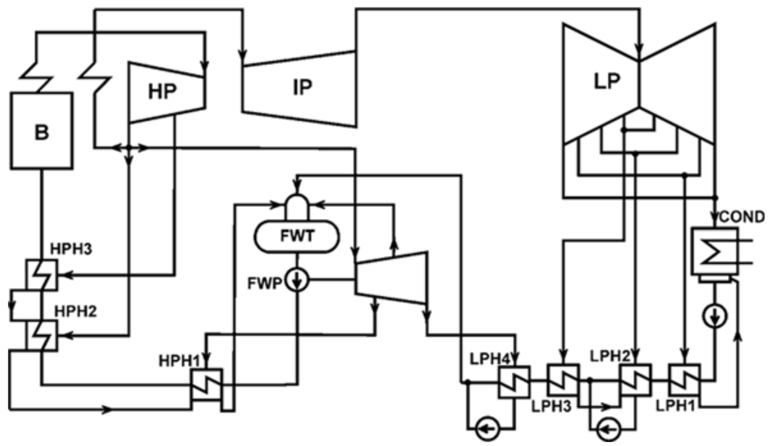

Figure 5 Diagram of the thermal cycle of a 900-MW unit. With feed pump driven by extraction-backpressure turbine: the idea of the MC. B, boiler; HP, high-pressure turbine; IP, immediate-pressure turbine; LP, low-pressure turbine; HPH3, HPH2 and HPH1, high-pressure feed water heaters; FWP, feed water pump; FWT, feed water tank + deaerator; LPH4, LPH3, LPH2 and LPH1, low-pressure feed water heaters; COND, condenser.

and the coal pulverizers. In each variant, identical operation and efficiency characteristics were adopted for corresponding facilities.

Results and discussion

The paper presents a comparison of the variants of the boiler feed pump drive for a conceptual 900-MW coal-fired unit for ultra-supercritical parameters. Table 3 shows the values of electric power needed to drive the feed pump for individual options depending on the live steam mass flow. In the electric motor option, the demand for electric power accounts for energy losses in the transformer, the supply network, the electric motor and in the frequency converter. For the remaining options with the feed pump turbine drive, the demand for electric power to drive the pump was calculated as the difference between the unit gross electric power for the option with an electric motor and the unit gross electric power for the other variants. The variant with the BPT shows the lowest demand for power for the 100% and 75% mass flow of live steam; for a smaller load of 50%, the CT requires the least power. However, for the EM, CT and BPT variants, the values are similar. A considerable reduction in the generated gross electric power occurred for the EBPT and the MC variants. This is because, in both of these cases, a relatively large steam mass flow is directed to the turbine driving the feed pump (for the MC option, it is more than 15% of the live steam mass flow), and it does not work in the main turbine. As the driving steam is taken into the turbine from a cold reheat line, it is not reheated in the boiler. Consequently, the amount of heat delivered into the cycle is reduced in comparison with the other variants.

Table 4 presents the unit consumption of the fuel chemical energy per unit of the generated net energy and the unit net electric power for three values of the live steam mass flow: 100%, 75% and 50% of the nominal mass flow. For the nominal load of the unit, the lowest unit consumption of the fuel chemical energy, i.e., the highest net efficiency of electric power generation was achieved for the MC variant, whereas the least efficient was the EM option. Figure 6 presents in the graph form the changes in the values of the unit net efficiency depending on the variant of the boiler feed pump drive.

Table 3 Demand for electric power to drive the feed pump

Drive variant of the feed water pump	Live steam mass flow/ nominal live steam mass flow		
	50%	75%	100%
Electric motor (EM)	9,844 kW_e	18,364 kW_e	32,660 kW_e
Condensing turbine (CT)	9,261 kW_e	18,239 kW_e	32,947 kW_e
Extraction-backpressure turbine (EBPT)	16,322 kW_e	28,723 kW_e	47,703 kW_e
Backpressure turbine (BPT)	10,041 kW_e	17,821 kW_e	30,169 kW_e
The idea of the Master Cycle (MC)	26,674 kW_e	44,441 kW_e	66,756 kW_e

Table 4 Unit net electric power (N_{elN}) and unit fuel consumption per unit of generated net energy (q_{enchN})

Drive variant of the feed water pump	Live steam mass flow/ nominal live steam mass flow					
	50%		75%		100%	
	N_{elN} (kW$_e$)	q_{enchN} (kJ/kWh)	N_{elN} (kW$_e$)	q_{enchN} (kJ/kWh)	N_{elN} (kW$_e$)	q_{enchN} (kJ/kWh)
Electric motor	478,980	7,847	701,798	7,684	908,255	7,636
Condensing turbine	479,719	7,835	702,200	7,679	908,461	7,632
Extraction-backpressure turbine	472,875	7,849	692,001	7,677	894,126	7,620
Backpressure turbine	479,001	7,819	702,686	7,656	911,273	7,608
The idea of the Master Cycle	462,999	7,854	676,888	7,666	875,774	7,581

The lines in the graph correspond to the set values of the live steam mass flow produced by the boiler. For lower values of the live steam mass flow, the CT variant turned out to be much better. For the MC and EBPT configurations, there is a bigger fall in the unit efficiency as the load decreases than for the others. This is probably due to the fact that turbines in this configuration have a large impact on the operation of regenerative exchangers where the steam from their bleeds and outlets is directed. Whenever the mass flow and the pressure of the generated steam decrease, the demand for power of the boiler feed pump falls substantially. Owing to that, the mass flow of the steam reaching the driving turbine also decreases significantly, and as a result, the pressures and steam mass flow at its bleeds and outlet decrease as well. Less steam flows into regenerative exchangers, so less heat is given up to the water that is being heated. The situation would be different if the steam mass flow feeding the turbine was increased, and the resulting surplus of power was given up in the auxiliary generator. However, as it was mentioned before, there is a problem with the difference in rotation speed between the feed pump and the generator. The pump operates at high speeds which change according to load, whereas the generator has to maintain a steady synchronous rotation speed.

Conclusions

The analysis showed that for the assumptions adopted for the calculations of a 900-MW ultra-supercritical unit, the highest net efficiency of electric power generation with a nominal steam mass flow had been achieved for the MC variant. It is by 0.34% point higher than the one obtained for the feed pump driven by an electric motor. According to Blum et al. [7], the application of such solutions gives much better results if they are combined with the use of dual steam reheat, where the problem of temperature accumulation in regenerative exchangers is more significant.

For smaller mass flows of generated steam, the cycle with a BPT features the highest efficiency. This type of

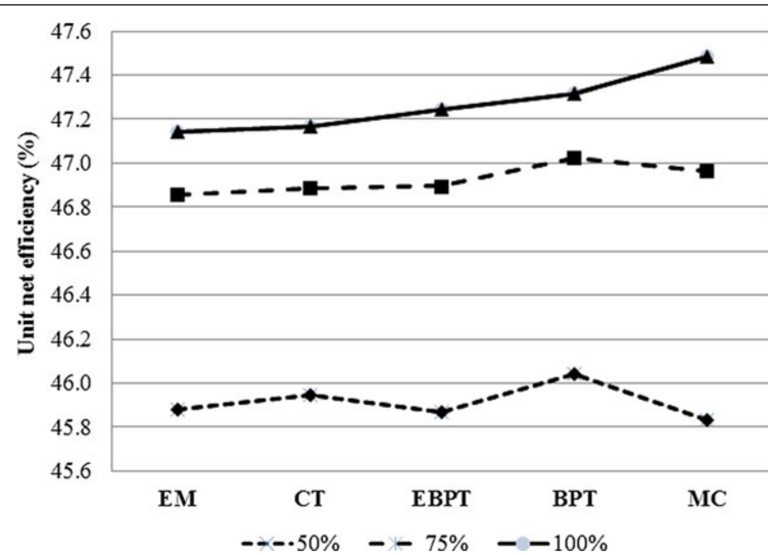

Figure 6 Net efficiency of a 900-MW unit electric power generation. For individual feed pump drive options depending on the live steam mass flow. EM, electric motors; CT, condensing turbine; EBPT, extraction-backpressure turbine; MC, master cycle.

solution might, however, entail higher investment expenditures due to very high parameters of the inlet steam (reheated steam). The differences in the unit net efficiency for variants using typical drive configurations, EM or CT, are very slight.

The load schedule of the unit should also have a considerable influence on the selection of the boiler feed pump drive. Assuming a longer operation of the unit under lower loads would exclude the application of the EBPT and MC variants due to a substantial decrease in the unit efficiency with load.

The choice of the optimum option of the boiler feed pump drive has a significant meaning from the point of view of reliability and availability of a power unit, the amount of investment expenditures and the net efficiency of electric power generation. Due to that, for each new investment, a detailed technical-economic analysis of the possible solutions has to be conducted.

Competing interests
The authors declare that they have no competing interests.

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Authors' contributions
KS carried out the calculations for all 900-MW power unit configurations, participated in the sequence alignment and drafted the manuscript. SD conceived of the study and participated in its design and coordination, and helped draft the manuscript. HŁ participated in the design of the study and helped draft the manuscript. All authors read and approved the final manuscript.

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References
1. Buchta, J, Pawlik, M, Oziemski, A, Kotlicki, T, Wawszczak, A: Potrzeby własne bloku nadkrytycznego. In: Kosman, G., Rusin, A., Taler, J., Pawlik, M. (eds.) Zagadnienia projektowania i eksploatacji kotłów i turbin do nadkrytycznych bloków węglowych, pp. 390–394. Politechniki Śląskiej, Gliwice (2010)
2. Laudyn, D., Pawlik, M., Strzelczyk, F.: Elektrownie. Naukowo-Techniczne, Warszawa (2005)
3. Westhuizen, W, Cattaert, T: Power station pump selection: part 2. Worlds Pump. **1**, 14–17 (2010)
4. Enery-Tech.Consider dual-driven boiler feed pumps for coal plants with capacity greater than 500 MW. http://www.energy-tech.com/article.cfm?id = 18376&PageNum = 1 (2008). Accessed 10 January 2011
5. Szulc, Z: Regulowany napęd elektryczny pompy wody zasilającej o podwyższonej pewności zasilania. (2008). Elektro.info. http://www.elektro.info.pl/artykul/id2534,regulowany-naped-elektryczny-pompy-wody-zasilajacej-o-podwyzszonej-pewnosci-zasilania. Accessed 10 January 2011
6. www.voilth.pl. Zastosowanie przekładni hydrodynamicznych Voith w napędach pomp wody zasilającej nowych bloków energetycznych. http://www.voith.pl/index.php?id_strony=302&id=241&idmain=26. Accessed 10 January 2011
7. Blum, R, Bugge, J, Kjaer, S: USC 700°C power technology—a European success story. VGB PowerTech. **26**, 4 (2009)
8. Blum, R, Bugge, J, Kjaer, S: Development of a PF fired high efficiency power plant (AD700). In: (ed.) Proceedings of the Riso International Energy Conference "Energy Solutions for Sustainable Development. Riso R-1608 (EN), Denmark (2007). http://130.226.56.153/rispubl/reports/ris-r-1608_69-80.pdf. Accessed 10 January 2011
9. Pawlik, M: Elektrownie opalane węglem w świetle polityki ograniczania emisji CO_2. Biuletyn Techniczno-Informacyjny Zarządu Oddziału Łódzkiego Stowarzyszenie Elektryków Polskich **2**(45), 1–36 (2009). http://sep.p.lodz.pl/biuletyn/sep_2_2009.pdf

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